Mars Exploration Rover Project

2001 Mars Odyssey - Mars Exploration Rover Relay Link Interface Control Document

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2001 MARS EXPLORATION ROVER PROJECT

2001 Mars Odyssey - Mars Exploration Rover Relay Link Interface Control Document

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1 Introduction

1.1 Scope

This document describes the interface used to exchange data in the relay link between the 2001 Mars Odyssey Orbiter (referred as Odyssey or orbiter in this document) and the two Mars Exploration Rovers (MER) while operating on the surface of Mars. In addition Odyssey will provide a Doppler service that will contribute to position determination of the two rovers on the surface of Mars.

In this *Return Link* refers to the transfer of data from the MER to the ground through the orbiter. *Forward Link* is the opposite direction of the data flow. We refer to the MER-orbiter link as *Proximity Link* and to the orbiter-ground link as *Deep Space Link*. In addition typically *command data* is exchanged in the forward link, *telemetry data* in the return link.

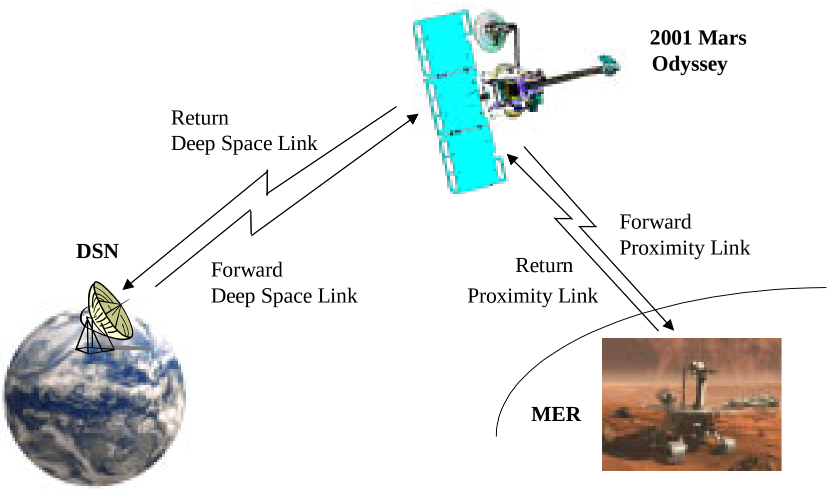


Figure 1. Relay Service Architecture

1.2 Reference Documents

- MER - 2001 Mars Odyssey Memorandum of Agreement, MER 420-9-140, D-20137, Jan - 2001
- 2001 Mars Odyssey Relay Data Service, PD 722-803, JPL D-19591, April 2001
- MER UHF Subsystem Requirements Specification, ES 518558, Rev. A, November 2001
- Proximity-1 Space Link Protocol, CCSDS 211.0-R-2, January 2000

2 Specifications Relative to Proximity-1 Link Protocol

The proximity link between MER and Odyssey follow the CCSDS draft recommendations for the Proximity-1 Space Link Protocol[1] with a few exceptions.

The physical layer provides the specification to exchange information at the bit level (including convolutional coding) between MER and Odyssey. The data layer provides the capability to establish a compatible link and to transfer information reliably.

2.1 Physical Layer

2.1.1 Frequencies

- Single forward and return frequencies
- Forward frequency 437.1 MHz
- Return frequency 401.585625 MHz
- Hailing frequency 437.1 MHz

2.1.2 Modulation

- PCM/Bi-Phase-L/PM
- Residual Carrier with a modulation index of 60° (±10% for MER, ±15% for Odyssey)

2.1.3 Data Rates

- Forward 8 kbps
- Return 8, 32, 128, 256 kbps

2.1.4 Convolutional Encoding

- Return link only
- Rate 1/2 with constraint length 7, non-inverted G2

2.1.5 Carrier Frequency Stability Requirement

- MER 2 ppm over temperature, 1 ppm for aging per year
- ODY 2 ppm over temperature, 1 ppm for aging per day

2.1.6 Doppler Tracking

- MER Carrier acquisition -5/+6 kHz within 1 sec, carrier tracking ±8 kHz
- ODY Carrier acquisition -6/+7.5 kHz within 1 sec, carrier tracking ±11 kHz

[1] Proximity-1 Space Link Protocol, CCSDS 211.0-R-2, January 2000.

2.2 Data Link Layer

The frame layer adds reliability to the proximity link and also can be used to establish a link in a compatible mode between MER and Odyssey. This section will give an overview of the frame layer, while the details of the implementation are contained in Appendix A.

The basic data unit for transmission is called Proximity Link Transfer Unit (PLTU), which is composed by an Attached Synchronization Marker (ASM), a transfer frame and a Cyclic Redundant Code (CRC). The 3-byte ASM is used to identify the beginning of the PLTU, while the CRC is used to flag errors occurred during the transmission of the PLTU.

PLTU

ASM	*Transfer Frame*	*CRC*
3 bytes	up to 1024 bytes	4 bytes

Transfer Frame

Header	*Data Field*
5 bytes	up to 1019 bytes

Figure 2. PLTU and Transfer Frame

The data exchanged in the link is formatted into a transfer frame with a header indicating the lander SCID, the frame sequence number and the length of the frame. The SCID is used to establish the link and to verify that the communication session is with the intended landed spacecraft. The frame sequence number is used to verify that the frames are received in the correct sequence in the reliable bit stream mode.

Acknowledgments (a particular type of proximity transfer frame called Proximity Link Control Word, PLCW) will be sent in response to the reception of the frame indicating the next expected sequence number.

Another type of transfer frame, called Directive Protocol Data Unit, is send by Odyssey to MER in order to establish the link in a compatible mode. See the next paragraph and Appendix A for details.

2.2.1 Link Establishment

The frame layer protocol will be used for establishing a link in a compatible mode between Odyssey and MER.

The link is always initiated by the orbiter. When commanded to, the orbiter will transmit at 8 kbps a Directive PDU (also called Command Beacon, see Appendix A) which specifies the mode to be used during the communication session (data rate, coding, …).

Three options are available for link establishment independent of the transceiver mode:

1. PSK Command Beacon - the directive is sent uncoded at 8 kbps with PSK modulation
2. FSK Command Beacon - the directive is sent uncoded at 8 kbps with FSK modulation
3. Disable Command Beacon - the directive is not sent; the transceivers at the two ends of the links have to be set in a compatible mode by the respective flight computers - this mode can be used to transfer data in the link without hand-shaking between the two transceivers.

PSK will be used in nominal operational scenarios. In this case the sequence for link establishments is as follows:

- orbiter transmits a carrier only signal lead (Continuous Wave, CW) for about 1 s to aid carrier acquisition
- orbiter sends an 4096-bit long idle-pattern (alternating '1' and '0') at 8 kbps in order to aid the bit synchronization at the receiver
- the orbiter transmits the Directive PDU (17-bytes long)
- the orbiter will switch its transmission to the data rate contained in the Directive PDU and send another second of CW followed by 4096 bits of idle-pattern - this is followed by either a transfer frame if there are command data to send or by an idle pattern
- during this time the orbiter waits for a response from the lander for a total of 2 s starting with the transmission of the second CW: if no response is received the transmitter cycles off for 2 s and then repeats the sequence (with a period of about 5.5 s for PSK) until the link is established or the orbiter transceiver is commanded to a different mode
- If MER correctly receives the Directive PDU sent by the orbiter it will set its transceiver as commanded by Odyssey and start transmitting - if the orbiter receives a response from the lander in those 2 s the link is established - MER will pre-append the CW and 4096 idle-pattern to every data transmission in order to aid the signal acquisition by the orbiter.

The use of FSK command beacon for the link establishment follows the same timeline, but it does not require the CW lead and its idle pattern is 512 bits long instead of 4096 bits.

If the link is lost during a pass (that is if the bit synchronization is lost) the link establishment sequence detailed above will start again, as long as the orbiter transceiver is not set to Disable Command Beacon.

Table 5 summarizes the timeline for PSK link establishment in the case where the forward link is always maintained at 8 kbps and no response is received from the Surface Element (SE).

Table 1. Timeline for Link Establishment, Typical Scenario with PSK modulation

Time Interval	Duration (ms)
CW	1000
Idle-Ready	512
Hail PDU	17
CW	1000
Idle Ready	512
Idle-Tail of Data	488
Transmitter Off	2000
Total Time	**5.529 seconds**

2.3 Available Modes

The relay link will operate in the following modes:

- Stand-by
- Reliable Bit Stream Mode
- Message by-pass
- Unreliable Bit Stream
- Canister
- Tone Beacon

All modes can be commanded separately from the transmission and receiving part of the transceiver with the exclusions listed in the following Table.

Table 2. Excluded Combinations of Transmitting and Receiving Modes

Transmit	Receive
Stand-by	Reliable
Reliable	Unreliable
Reliable	Tone Beacon
Reliable	Canister
Unreliable	Reliable
Tone Beacon	Reliable

2.3.1 Stand-by Mode

Transmit stand-by mode prevents transmission (except if Command Beacon is enabled). Receive stand-by is the power-on status that waits for a command beacon in order to start a session.

2.3.2 Reliable Bit Stream Mode

This is the nominal mode to be used between MER and Odyssey. The reliable bit stream mode ensures the error-free transmission of the input bit stream to the receiving end, utilizing the frame layer structure described in the previous section and using an Automatic Repeat Request (ARQ) protocol. The orbiter will indicate in the command beacon that reliable bit stream mode will be used in the session with MER.

- ♦ the Frame Sequence Number (a field in the frame header) will permit the receiving end to verify that the packets are received in the proper order -since the counter has to be synchronized between the two ends of the link, both MER and Odyssey need to reset the counter to zero at the beginning of every (operationally this is done by turning off and on the transceiver)
- ♦ the CRC appended after the frame will allow the receiver at the opposite end of the link to check if any bit of the packet suffered an error during transmission - if no errors are detected a Proximity Link Control Word (PLCW, see Appendix A) will be returned indicating an expected frame sequence number incremented by one, otherwise the sequence number will stay the same.

In the reliable bit stream mode both Odyssey and MER implement a Go-Back-2 protocol, which permits transmission of the frame *N+1* while waiting the acknowledgments for the frame *N*. In the case where an acknowledgment for frame *N* is not received before the end of the transmission of the frame *N+1*, the transmitter will keep sending the two transfer frames until correct reception of frame *N* is acknowledged.

The length of frame transmitted is restricted automatically as described in Table 4; based on the data rate of the forward and return link. This is done in order to keep a balance in the Go-back 2 ARQ scheme between transmitted packets and return PLCW when full duplex communication is in place, as is shown in Table 5.

Table 3. Length of Transfer Frame versus Bit Rate

Forward Bit Rate [kbps]	Return Bit Rate [kbps]	Forward Frame Length [bytes]	Return Frame Length [bytes]
8	8	1024	1024
8	32	238	1024
8	128	42	1024
8	256	9	238
32	8	1024	1024
32	32	1024	1024
32	128	238	1024
32	256	107	1024
128	8	1024	42
128	32	1024	238
128	128	1024	1024
128	256	499	1024
256	8	1024	9
256	32	1024	107
256	128	1024	499
256	256	1024	1024

Table 4. Effective Data Rate for Full Duplex Communication

Forward Link					**Return Link**				
Bit Rate	**Frame Length (*)**	**Time to TX frame + PLCW**	**Effective Bit Rate**	**efficiency**	**Bit Rate**	**Frame Length (**)**	**Time to TX frame +PLCW (***)**	**Effective Bit Rate**	**efficiency**
bps	**bytes**	**s**	**bps**		**bps**	**bytes**	**s**	**bps**	
8000	1024	1.047000	7787	**97.3%**	**8000**	1024	1.047000	7787	**97.3%**
8000	238	0.261000	7158	**89.5%**	**32000**	1024	0.261750	31148	**97.3%**
8000	42	0.065000	4800	**60.0%**	**128000**	1024	0.065438	124593	**97.3%**
8000	9	0.032000	1946	**24.3%**	**256000**	1024	0.032719	249186	**97.3%**
32000	1024	0.261750	31148	**97.3%**	**8000**	238	0.261000	7158	**89.5%**
32000	1024	0.261750	31148	**97.3%**	**32000**	1024	0.261750	31148	**97.3%**
32000	238	0.065250	28632	**89.5%**	**128000**	1024	0.065438	124593	**97.3%**
32000	107	0.032500	25363	**79.3%**	**256000**	1024	0.032719	249186	**97.3%**
128000	1024	0.065438	124593	**97.3%**	**8000**	42	0.065000	4800	**60.0%**
128000	1024	0.065438	124593	**97.3%**	**32000**	238	0.065250	28632	**89.5%**
128000	1024	0.065438	124593	**97.3%**	**128000**	1024	0.065438	124593	**97.3%**
128000	499	0.032625	121199	**94.7%**	**256000**	1024	0.032719	249186	**97.3%**
256000	1024	0.032719	249186	**97.3%**	**8000**	9	0.032000	1946	**24.3%**
256000	1024	0.032719	249186	**97.3%**	**32000**	107	0.032500	25363	**79.3%**
256000	1024	0.032719	249186	**97.3%**	**128000**	499	0.032625	121199	**94.7%**
256000	1024	0.032719	249186	**97.3%**	**256000**	1024	0.032719	249186	**97.3%**

(*) pre-programmed in the MSP'01 Transceiver based on forward and return bit rates
(**) SE Transceiver can transmit a variable frame length up to 1024 bytes
but the data length in this coloumn provides maximum efficiency
(***) assumes that the SE transceiver insert 1 byte of pad after each frame

2.3.3 Message By-pass Mode

The use of this mode between MER and Odyssey is not required and will not be described in this document.

2.3.4 Unreliable Bit Stream Mode

In this mode the frame layer protocol is not used , but the Set directive can still be sent to establish the link in a compatible mode.

The UHF Transceiver can be set to unreliable mode independently for its receiver and transmitter portions.

When one of the two transceivers is set to transmit in unreliable bit stream mode, it will simply transmits data continuously when the transceiver buffer is not empty (at least one byte is present). The transceiver does not wrap the data in Proximity-1 transfer frames, so no acknowledgments are exchanged in this mode. Prior to data transmission 1 s CW (PSK transmission only) and the bit sync preamble (4096 bits for PSK, 512 bits for FSK) will be sent by the radio. Transmission will stop when the FIFO buffer is empty or the transceiver is commanded in a different mode. The transmitter will cycle on and off based on the presence or not of data in the transmit buffer of the transceiver.

When the transceiver is set to receive in unreliable bit stream mode, the received data (demodulated and optionally decoded without any check for the frame layer) will be output directly to the avionics without buffering.

The unreliable bit stream mode can be used if some failure of the proximity protocol is suspected, so that the reliable bit stream mode cannot be employed.

2.3.5 Canister Mode

The use of this mode between MER and Odyssey is not required and will not be described in this document.

2.3.6 Tone Beacon Mode

Tone beacon mode offers for the transmission from the orbiter of the following CW (pure tones) frequencies for the orbiter:

- 437.1000 MHz
- 440.7425 MHz
- 444.3850 MHz
- 448.0275 MHz

With MER the only use is for the 437.1 MHz tone to perform 2-way Doppler measurement without sending commands from the Orbiter allowing more power in the carrier.

When the MER transceiver is commanded into transmit tone beacon it will always send a CW at 401.585625 MHz.

2.4 Doppler Measurement Service

The Doppler measurement on the incoming signal can be performed by the orbiter transceiver when it's configured in PSK receive mode and carrier lock is achieved.

The requirement for Odyssey is to provide measurement with 1 mHz accuracy every 5 seconds. The accuracy of this 5 seconds interval shall be better than 10 ms.

This is required for lander positioning on the Mars surface.

The Doppler measurement, when requested, is output by the transceiver every 5 seconds and it will be downlinked to the ground as part of the Odyssey engineering telemetry stream.

3 Relay Link Performance

3.1 MER

All power levels are specified at the common port of the diplexer

- RF Power > 39.0 dBm
- Receive Threshold < -113.5 dBm (8 kbps uncoded, BER=1E-6)
- Carrier Acquisition = +6/-5 kHz dBm within 1 sec for received power >-116 dBm
- Circuit Loss = 0.6 dB (TBC)
- Antenna Gain: monopole linearly polarized - see figure 5 for the preliminary pattern

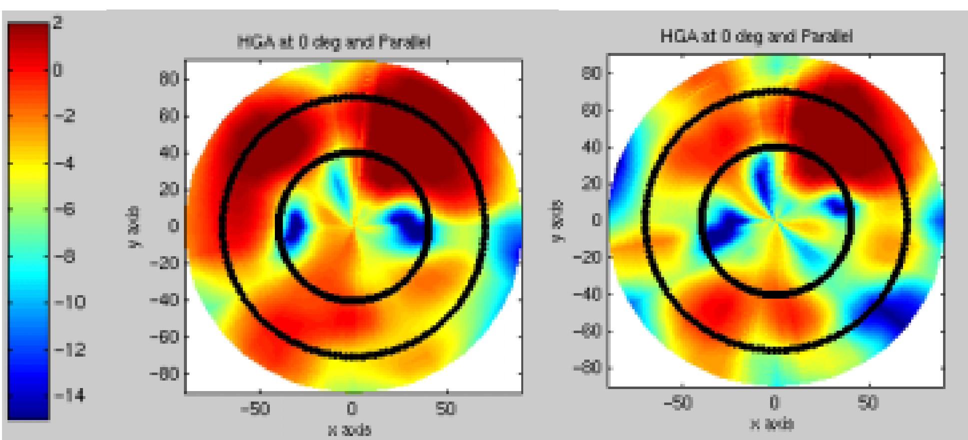


Figure 5. MER Antenna Pattern (in dBic at 401 and 437 MHz) measured on a mock-up of the rover.

3.2 Odyssey

All power levels are specified at the transceiver input and output ports

- RF Power > 40 dBm
- Receive Threshold < -110.5 dBm (128 kbps coded, BER=1E-6)

- Carrier Acquisition = +7.5/-6 kHz dBm within 1 sec for received power >-110 dBm
- Circuit Loss = 1.8 dB return link, 1.0 dB forward link
- Antenna Polarization: Right Hand Circular
- Antenna Gain: see picture below for measurement on the spacecraft mock-up

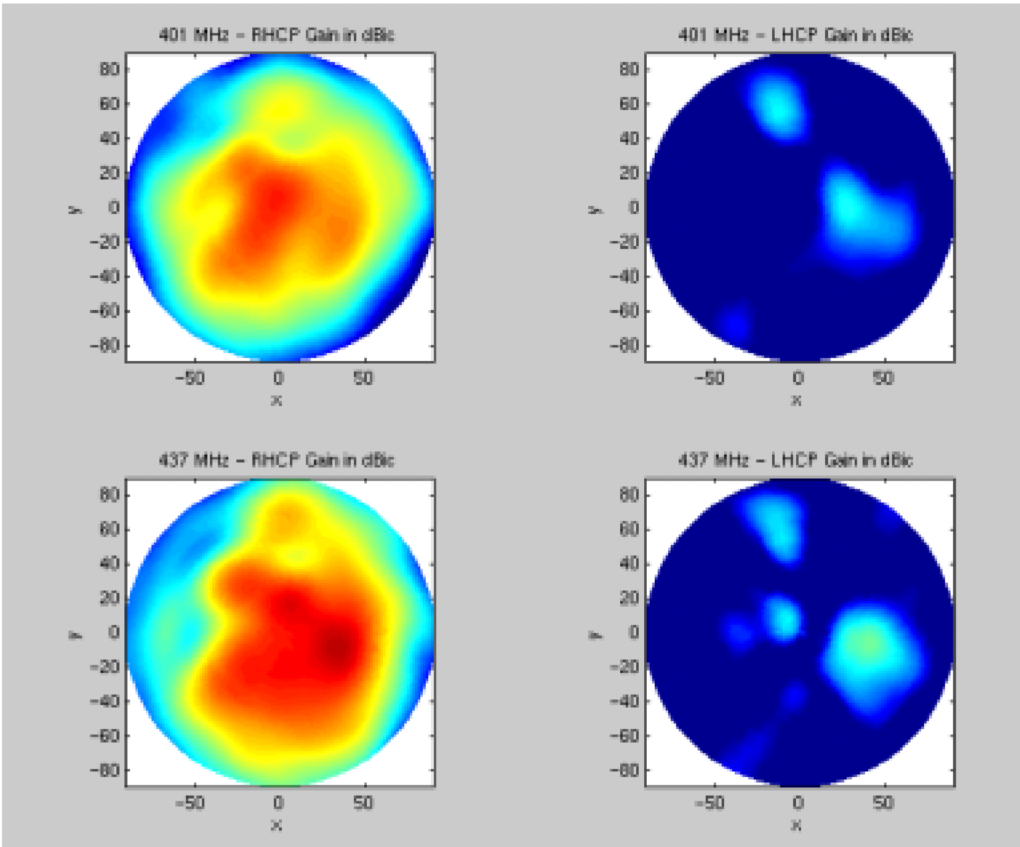


Figure 3. Measured Odyssey Antenna Gain at 401 MHz (Return) and 437 MHz (Forward)

Test conducted during cruise on the performance of the UHF subsystem assessed that:

- the total power in the forward link is 6 dB less than predicted before the flight
- the received BER vs. predicted SNR showed a degradation of 2 dB in the return link (still within the accuracy of the test conducted)

4 End to End Data Flow

This section will specify how the data is transferred between the MER spacecraft and the ground via the Odyssey orbiter.

4.1 Overview

The end to end data flow of data between MER and the ground via the orbiter is illustrated in Figure .

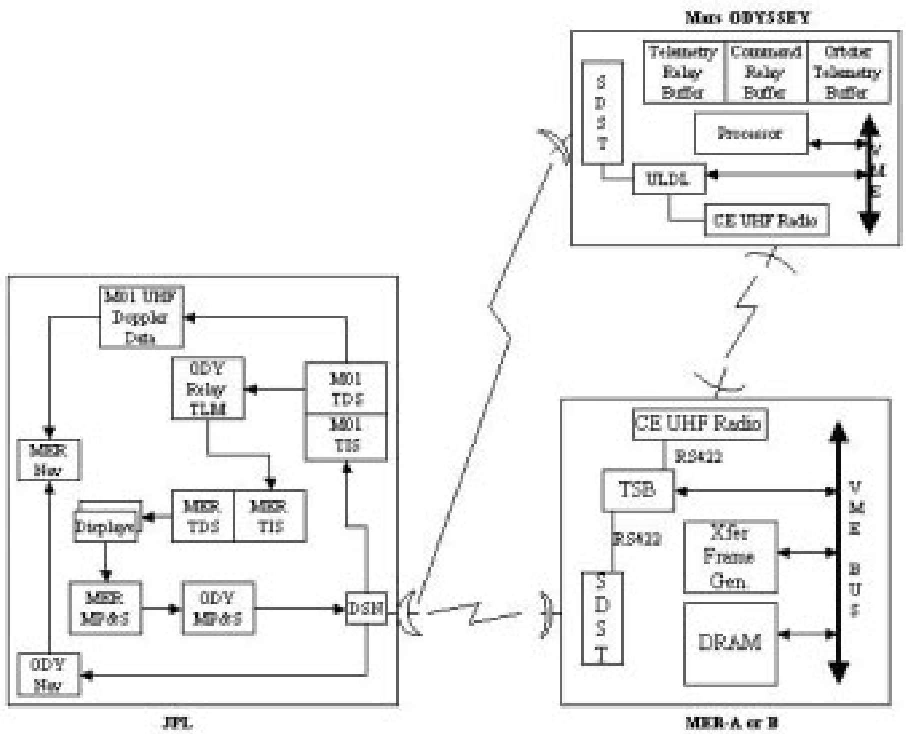


Figure 4. Relay Data Flow

MER telemetry data are formatted in MER transfer frames and sent to the Mars Odyssey via UHF link. Odyssey processes the received data as bit stream and packetizes the bit stream data into Odyssey relay packets. These packets are multiplexed with other Odyssey science packets and downlinked to the ground in Odyssey transfer frames. DSMS retrieves the Odyssey relay packets and send them through the MER telemetry processing system to be processed.

MER command load are generated into CLTU file that contains the bits and the same format as if it were being radiated to the spacecraft on the X-Band link. This CLTU file is uplinked to the Odyssey using

Mars 01's Non-interactive file uplink process. The content of this file is transmitted to the MER on the UHF link. The bits are passed on to the Telecom Support Board (TSB) as it would from the SDST.

UHF Doppler data and engineering data are collected on board the Mars Odyssey and packetized in ODY packets separately. These packets are stored in the Mars 01 telemetry data system and can be queried by the MER operations.

Figure illustrates the components involved in the data flow of relay data in the orbiter and a brief description is given below.

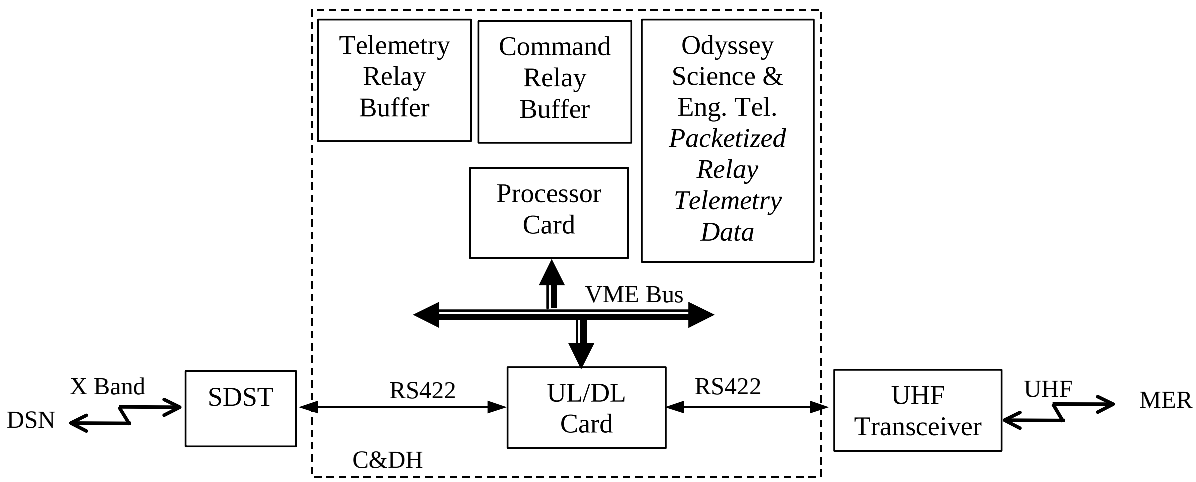


Figure 5. Relay Data Flow in the Orbiter

The UHF transceiver is the terminal for RF communications with MER and it also implements the Proximity Link protocol. The transceiver has a temporary data storage, with a 128 kbyte FIFO divided between the transmitting and receiving functions.

In the orbiter, the interface between the transceiver and the flight computer is a particular device called ULDL (Uplink/Downlink) card, which has its own FIFO.

The relay data is stored in a particular segment of the orbiter memory, called Relay Buffer, logically separated from other orbiter data (science measurement, engineering telemetry or commands).

A software change (ECR 84a) in the orbiter will implement the function of treating the relay telemetry data coming from MER as any other orbiter data including the creation of packets with a specific APID. This packet will then be subject to the same rules (prioritization, aging, …) as the other orbiter science and engineering data.

Communications with the ground will use X band via the Small Deep Space Transponder (SDST). The ULDL card is also the interface between the computer and the transponder.

4.2 Return Link

4.2.1 MER

Onboard MER, the transfer frame formatting depends on the UHF mode to be used. There are three UHF modes planned for the MER operation: (1) Reliable Bit Stream Mode, (2) One-way Mode, and (3) Unreliable Bit Stream Mode. One-way Mode is used for MGS relay during EDL and is not be applicable to this ICD.

4.2.1.1 Reliable Bit Stream Mode

The Reliable Bit Stream mode is the nominal UHF relay mode used for surface operations. In this mode, the 8800-bit transfer frame is used. The transfer frames are checksummed and a sync marker is placed at the front of each frame by the flight software, see Figure 3-3. The data bypass the telecom board R-S function and are put in the UHF transceiver's Transmit buffer. The UHF transceiver pulls the data bits from the Transmit buffer and generate a proximity-1 transfer frame, which is used to send to the relay orbiter and carries out the Go-back-2 protocol to ensure correct and complete transfer of data to the relay orbiter.

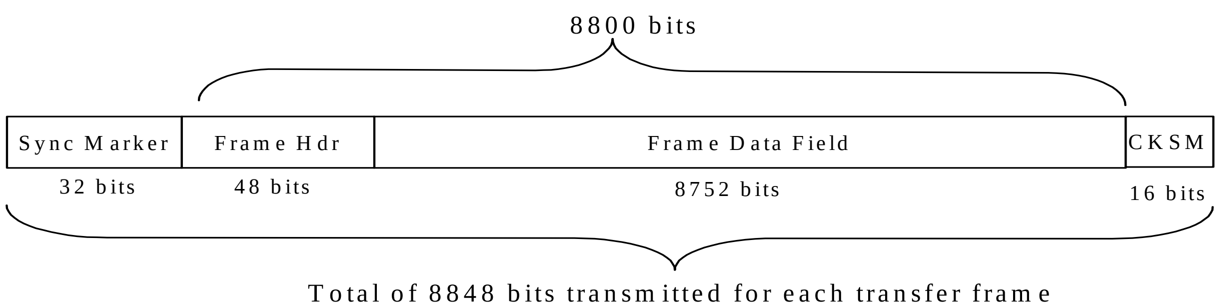


Figure 6. MER Transfer Frame Used in Reliable Bit Stream Mode

4.2.1.2 Unreliable Bit Stream Mode

The Unreliable Bit Stream mode is used when Reliable Bit Stream mode can not be operated; such as when two-way communication is not available, or bit error rate is too high to efficiently operate the go-back-2 protocol. In the unreliable bit stream mode, the 8800-bit transfer frame is used. The transfer frames are Reed-Solomon encoded and a sync marker is placed at the front of each frame, see Figure 3-4. The resulting data are then put into the UHF transceiver's Transmit buffer. The UHF transceiver pulls the data bits from the Transmit buffer and transmit the data stream to the relay orbiter.

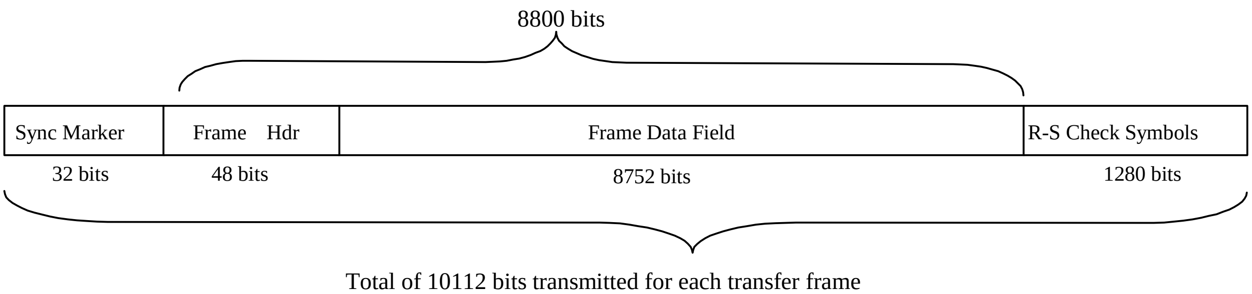


Figure 7. MER Transfer Frame Used in Unreliable Bit Stream Mode

4.2.2 ODYSSEY

On the Odyssey side, after the relay link is established, the orbiter UHF transceiver will demodulate and convolutionally decode (optional) the received signal from MER. The data is then routed through the ULDL card into a special buffer, called Telemetry Relay Buffer, in the flight computer DRAM.

MER's baseline design is based on the ECR 84a being implemented, tested, and uploaded to the orbiter spacecraft before the relay operations take place. In this approach, the relay telemetry data coming from MER will be formatted by the orbiter into source packets with a fixed length of 2189 bytes.

The APID of this packet will be used to distinguish data coming from the two MER spacecraft and also from other landers on Mars. APID = 45 (decimal) is used for the MER-1[2] rover, APID = 46 (decimal) is used for MER-2. These packets will then be subject to the same rules (prioritazion, aging, …) as the other orbiter science and engineering data. The relay packets are multiplexed with other orbiter packets into telemetry transfer frames including Reed Solomon encoding before sending the data to the SDST. The requirement, agreed by both MER and M'01, is to return the relay data to the ground and in the MER MSA within 10 hours of the end of a UHF link pass.

The end to end data flow in the return link is shown in Figure.

[2] MER-1 and MER-2 are used to identify the physical rovers that are being built. MER-A and MER-B are the designation of the missions with MER-A being the first launch and MER-B the second launch. It is planned to launch MER-1 first, thus MER-1 will be synonymous with MER-A. However, it is also possible that MER-2 be launched first, and then MER-2 and MER-A will be synonymous.

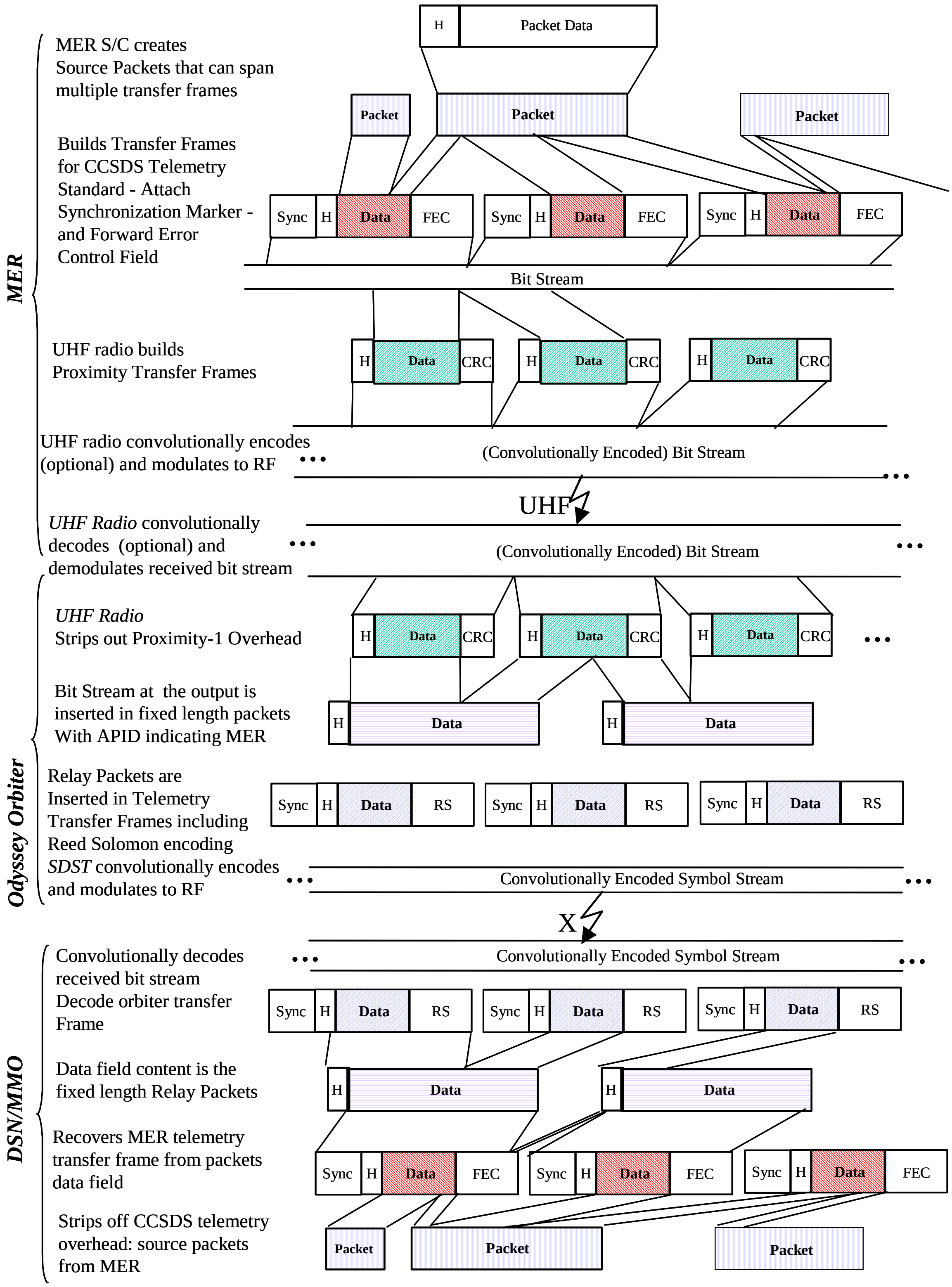


Figure 8. End to End Data Flow in Return (Telemetry) Link

4.3 Forward Link Data Flow

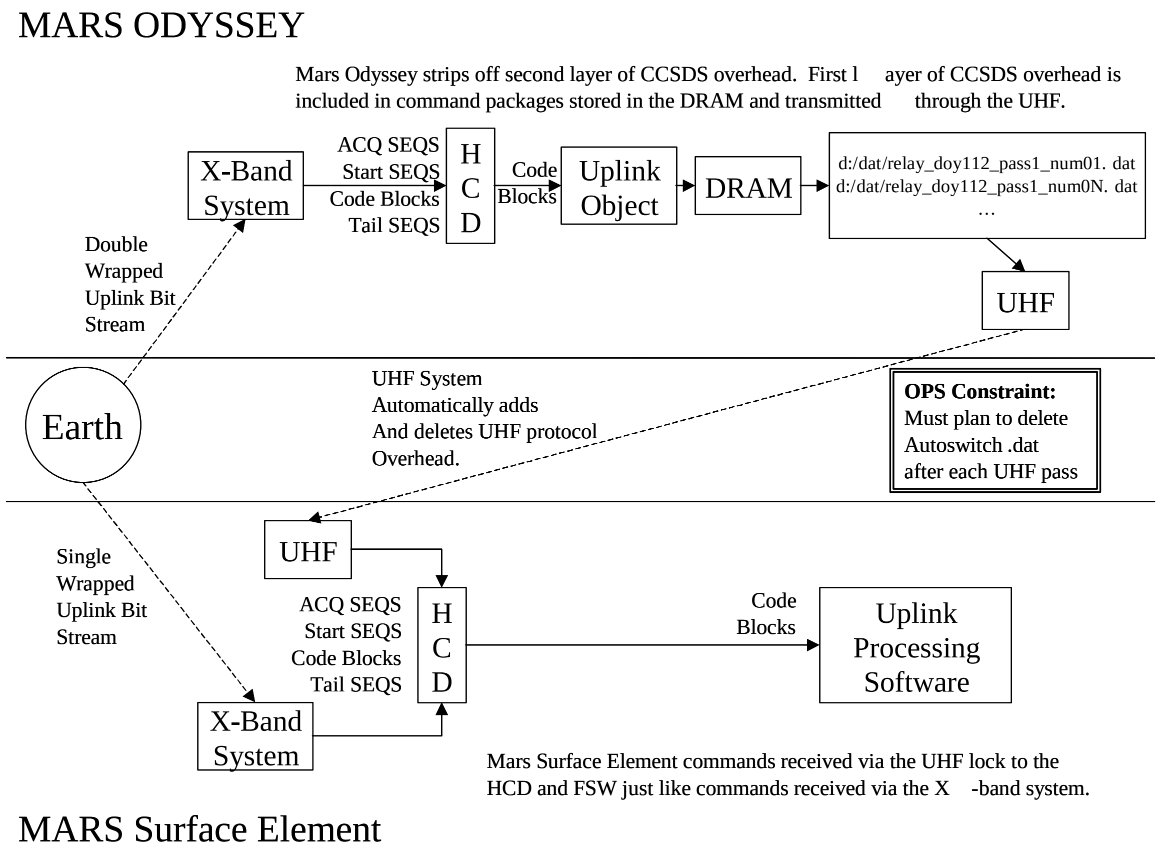


Figure 9. Forward Link overview

4.3.1 Relay Command Ground Processing

For the MER commands to be relayed through Odyssey, the commands must go through two processing steps on the ground.

The first step in this process is to create the command load intended for the MER. This command load is processed by the MER Integrated Sequence Team (IST) just as if it were to be uplinked to MER directly via the DFE link. This will result in a spacecraft command message file (SCMF) that contains: an acquisition sequence, followed by one or more CLTUs (start sequences, codeblocks, tail sequences), and idle sequences if applicable. The 176 bits of alternating 0's and 1's acquisition sequence are not needed for UHF relay; however if present, it wouldn't harm the spacecraft or command execution. For a normal DFE uplink to MER, this SCMF is what would be input to DSMS Space Link Extension (SLE) CLTU services that interface with the Deep Space Network (DSN) and uplink the command load to the spacecraft.

For relay operation, the SCMF file that results from 1st step is stored as a binary file for subsequent processing, for example:

1a) the 1st .scmf file placed on the DOM under M01/53/d_dat as "c01relay_doy112_pass1_num01.dat"

2a) the 2nd .scmf file placed on the DOM under M01/53/d_dat as "c01relay_doy112_pass1_num02.dat"

In the second step, these MER CLTU files are then input to the Odyssey uplink generations tools using the Non-Interactive File Load process (NIFL).

1b) send_frf –sc 53 –u 1000 –type ifl –target_dir d:/dat c01relay_doy112_pass1_num01.dat

2b) send_frf –sc 53 –u 1000 –type ifl –target_dir d:/dat c01relay_doy112_pass1_num02.dat

The files are radiated to the ODY and are stored in the Odyssey spacecraft file system as

1c) d:/dat/c01_relay_doy112_pass1_num01.dat

2c) d:/dat/c01_relay_doy112_pass1_num02.dat

Multiple CLTU files can be uplinked for one UHF pass.

4.3.2 Relay Command Orbiter Processing

Just before UHF pass 1 on DOY 112 an ODY onboard sequence copies the relay CLTU files into d:/dat/autoswitch.dat, as the following:

1. Suppress "file does not exist" EVR
2. FILE COPY d:/dat/c01_relay_doy112_pass1_num01.dat d:/dat/autoswitch.dat
3. FILE APPEND d:/dat/c01_relay_doy112_pass1_num02.dat d:/dat/autoswitch.dat
4. Unsuppress "file does not exist" EVR

The UHF pass is initiated by starting the uhf_cmd_xband.blk or uhf_cmd_relay.blk command blocks which are resident on board (See the Odyssey Mission Operations Guide and Block Dictionary for a full description of the commands contained within these blocks). In essence the Odyssey UHF is powered on and set to establish an UHF link with the Rover.

Once the UHF link with MER is established, when the downlink mode on Odyssey is set to RELAY_CMD indicating that Odyssey is to transmit commands to MER via the UHF, flight software will automatically command the ULDL card to a downlink path of UHF with Reed Solomon encoding bypassed. The ODY FSW then copies the contents of the autoswitch.dat to the UHF hardware buffer. The data reside in the UHF hardware buffer should look exactly like the original MER CLTUs created in the first step described above. The contents of the UHF hardware buffer which contains the MER command load will be transmitted to the MER Rover. It should be noted that if a DSN contact is in progress when this occurs, the DSN contact will be interrupted for the period of time needed to transmit the commands from Odyssey to MER.

After the UHF pass, the Odyssey will delete the d:/dat/autoswitch.dat and all uplinked relay command files (e.g. d:/dat/c01_relay_doy112_pass1_num01.dat and d:/dat/c01_relay_doy112_pass1_num02.dat) so that it does not inadvertently get used for the next pass.

3.3.3 Relay Command Rover Processing

All data formatting needed to transmit the command loads via the UHF from Odyssey to the MER will be done by the UHF system on Odyssey and undone by the UHF system on MER. Hence, the command load routed from the UHF transceiver to the Telecom Support Board (TSB) on MER is the same format as from the SDST to TSB. Figure 3-7 below illustrates the command data flow as processed on MER.

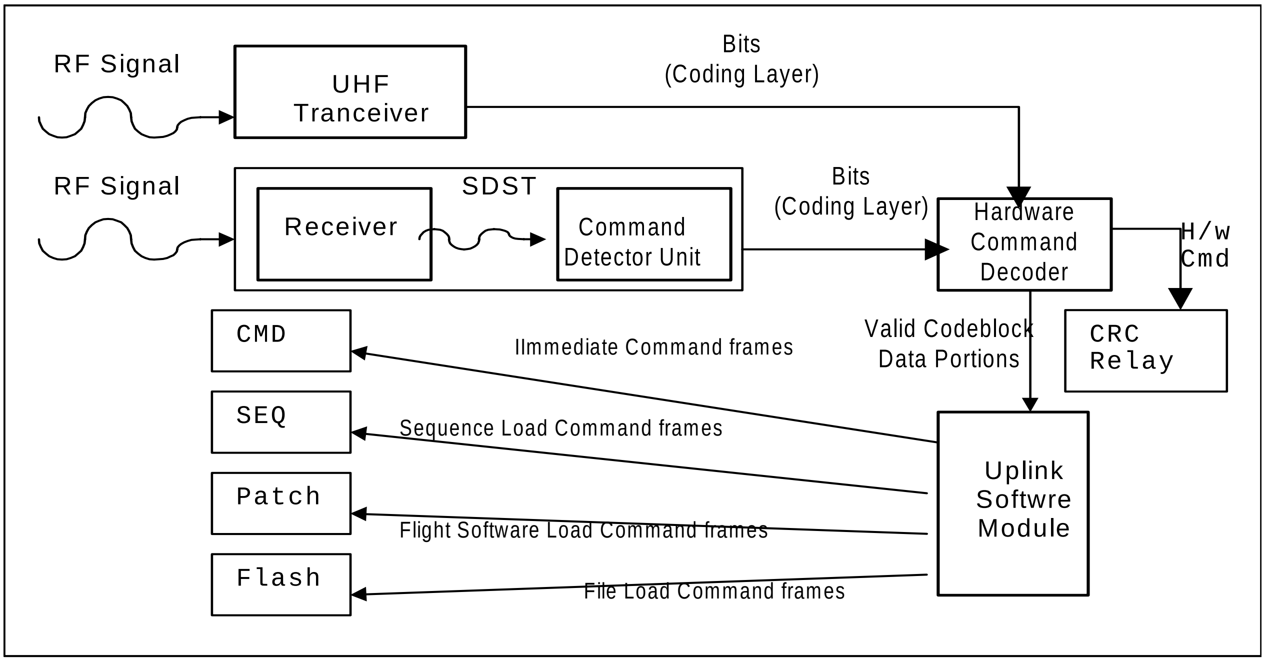
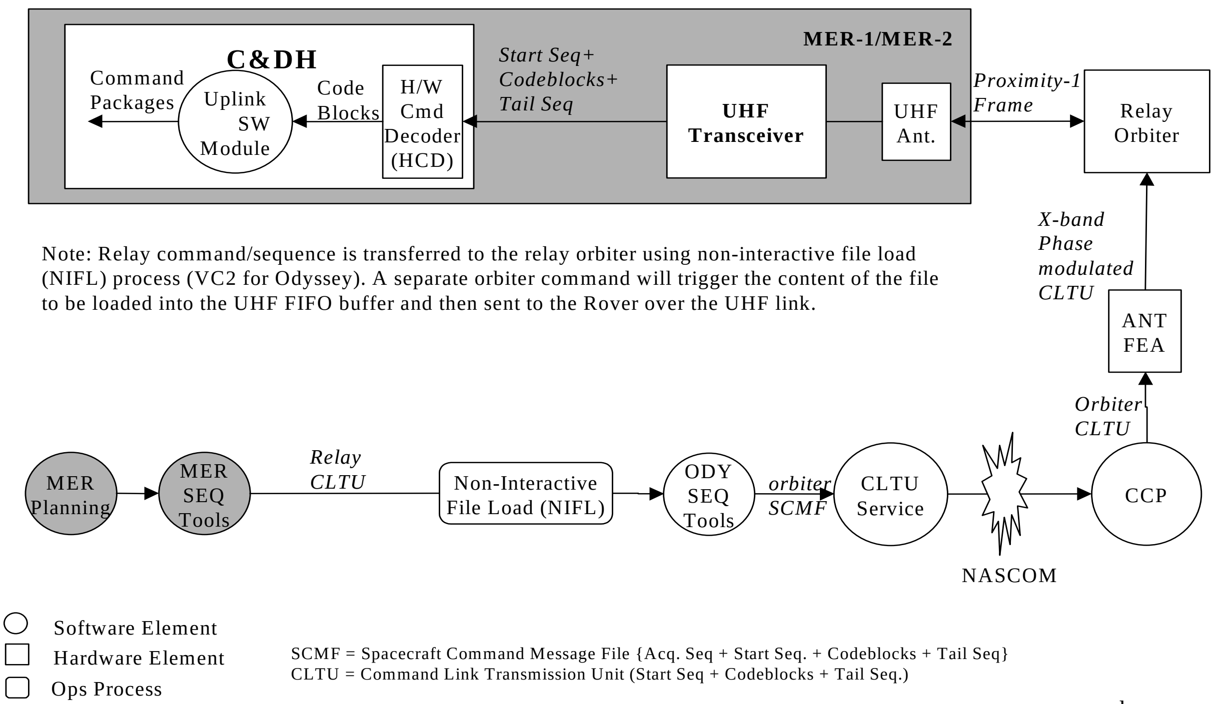


Figure 10. Command Processing on MER



Note: Relay command/sequence is transferred to the relay orbiter using non-interactive file load (NIFL) process (VC2 for Odyssey). A separate orbiter command will trigger the content of the file to be loaded into the UHF FIFO buffer and then sent to the Rover over the UHF link.

SCMF = Spacecraft Command Message File {Acq. Seq + Start Seq. + Codeblocks + Tail Seq}
CLTU = Command Link Transmission Unit (Start Seq + Codeblocks + Tail Seq.)

nk

Figure 10. Relay Command End-to-End Data Flow

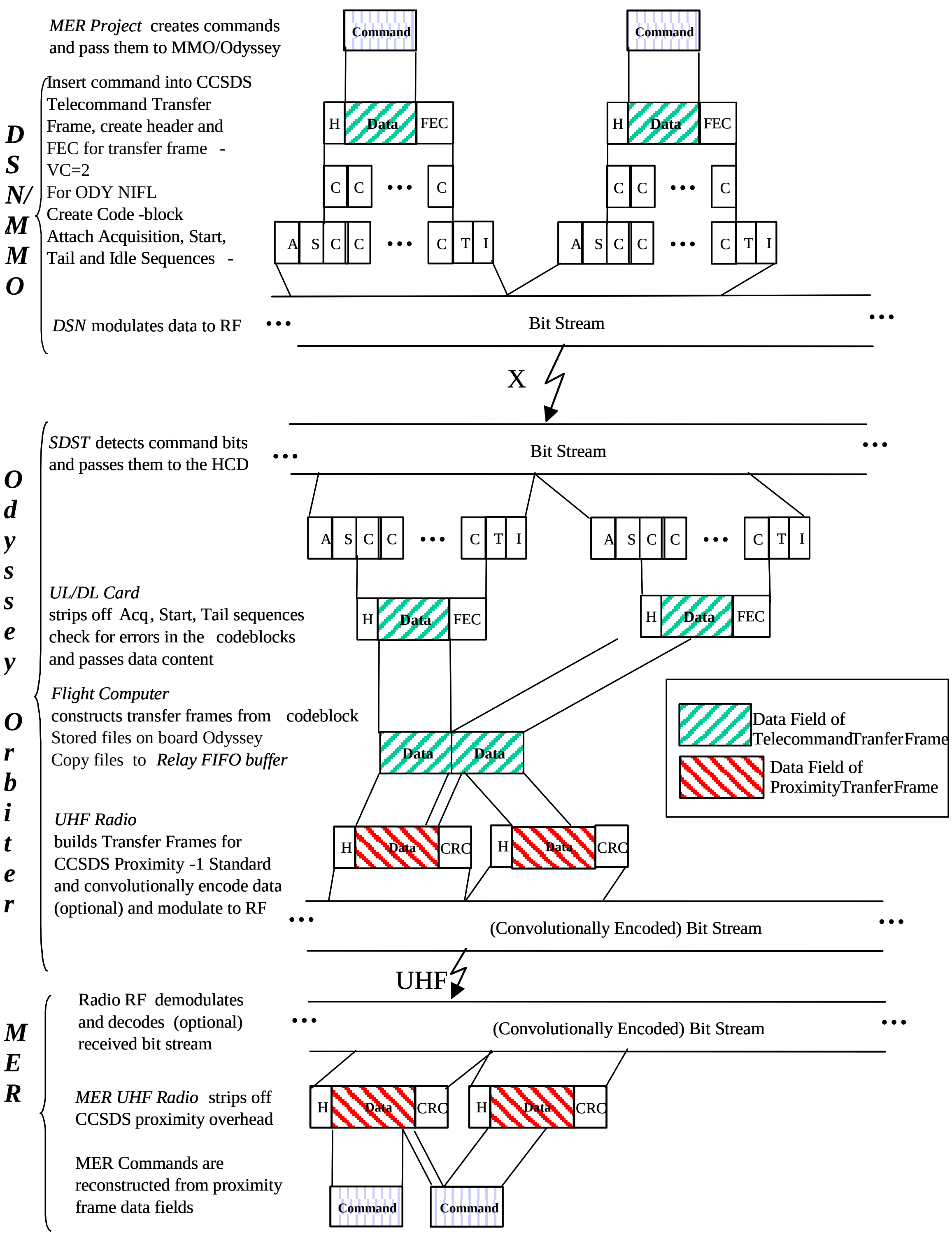


Figure 11. Relay Command End to End Data Formats Transformation

4.4 Odyssey UHF Engineering and Doppler Data

All the information contained in the Odyssey engineering telemetry related to the relay subsystem are also needed by the MER project in order to assess the time of link establishment, the duration of the relay link and to compare actual performance to the telecom predicts.

In addition the Doppler data collected at UHF by Odyssey and relative time-tagging information will be used by the MER project for rover positioning. The UHF Doppler data is packetized in APID 35 (decimal) as shown in Figure 3-10

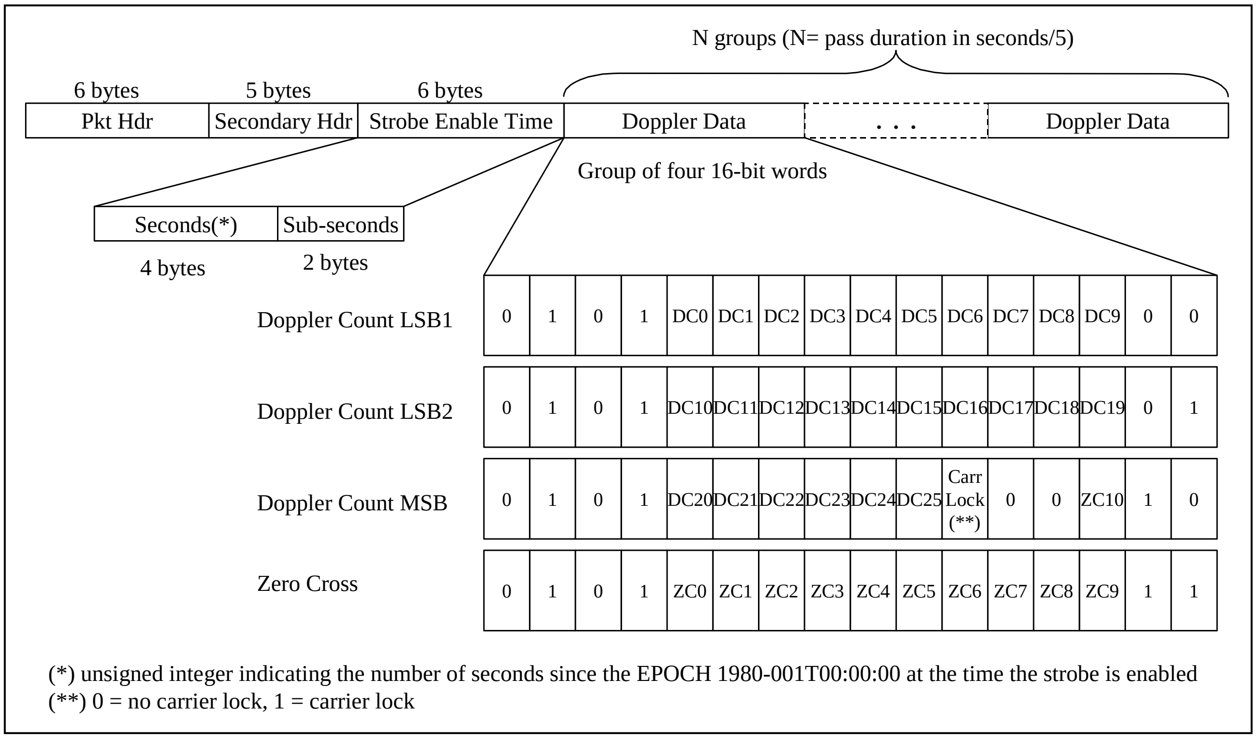


Figure 12. Odyssey UHF Doppler Data Format (APID = 35)

5 Compatibility Verification

This section presents a summary of the compatibility verification of the relay link between MER and Odyssey. MER test plan and procedures will detail this verification.

5.1 RF and Proximity Protocol Compatibility

The compatibility at RF and Proximity Protocol level between the Odyssey flight unit transceiver and MER engineering development units (EDU) was verified in several occasion (vendor acceptance tests, UHF functional and integration tests, sequence verification test, …) during the orbiter ATLO flow. MER UHF EDUs are functionally equivalent to the flight units.

The MER UHF flight units will be tested during acceptance and functional tests with the Odyssey UHF Test Set at MER ATLO site in JPL. Odyssey UHF Test Set consists of the Odyssey orbiter flight software, the UHF transceiver and the Odyssey TTACS.

5.2 End to End Compatibility

Compatibility of the end to end data flow between MER and Odyssey will be verified during MER ATLO. This test will use the MER flight and ground system, the Odyssey UHF Test Set. Mars 01 project should provide support to the MER project for this test, including the UHF Test Set setup and take down at MER ATLO, the UHF Test Set operations training, and technical assistance during the test.

Appendix A: Proximity Protocol Frame Layer Implementation

This Appendix will detail the frame layer structure of the Proximity protocol between MER and Odyssey.

Proximity Link Transfer Unit (PLTU)

The Proximity Link Transfer Unit (PLTU) is composed of:

- an Attached Synchronization Marker (ASM) composed by 24 bits defined as 'FAF320' in hexadecimal notation
- a *Transfer Frame* as described below
- an attached CRC (Cyclic Redundancy Code) calculated on the transfer frame (header and data field) with the following generator polynomial:

$$x^{32}+ x^{23}+ x^{21}+ x^{11}+ x^{2}+1$$

Transfer Frame

The transfer frame is composed of 5 bytes of header followed by a data field with 1 to 1019 bytes. The header is composed by 10 fields as described below (see Figure 8 for an illustration of the PLTU and Transfer Frame Format):

	ASM	*Transfer Frame*	*CRC*
PLTU	3 bytes	up to 1024 bytes	4 bytes

	Header	*Data Field*
Transfer Frame	5 bytes	up to 1019 bytes

	Version Number	*QoS*	*PDU Type ID*	*Data Field Construction ID*	*S/C ID*	*VC ID*	*Port ID*	*Source Destination Flag*	*Frame Length*	*Frame Sequence Number*
Header bits	0,1	2	3	4, 5	6-15	16	17-19	20	21-31	32-39

Figure A-1. Format of the Proximity Link Transfer Unit, of the Transfer Frame and its Header

- Transfer Frame Version Number. Bits 0,1 contain the binary value '10'
- Quality of Service (QoS) Indicator, bit 2:
  - '0' specifies that the frame is transmitted using the reliable bit stream mode - the acceptance of the frame is subject to the CRC check, S/C ID and frame sequence number validation (see frame length field description)
  - '1' indicates that the transfer frame is transmitted using the message-by pass - the acceptance of the frame is subject only to the CRC check[3]
- Protocol Data Unit (PDU) Type ID. Bit 3, if:

[3] use of this mode in the MER-Odyssey link is TBD.

– '0' indicates that the data fields contains User Data

– '1' specifies that the data field contains control information for the proximity link (see the following section, External PDU).

The following table summarize the mode corresponding to the setting of the QoS and PDU Type ID fields.

Table A-1. QoS and PDU Type ID Fields vs. transmitting mode

QoS	***PDU Type ID***	**Mode**
0	0	User Data / Reliable Bit Stream mode
0	1	Reserved
1	0	User Data / Message By-Pass mode
1	1	PLCW (ACK) or Directive PDU

In the reliable bit stream mode, the data field of the transfer frame contains user data that will be sent in a sequence controlled mode over the link. In the message by-pass mode the content is still user data, but the received frame is subject only to CRC check. When Bits 2 and 3 of the header are '11' the frame contains either the ACK (called PLCW, Proximity Link Control Word in the standard) of the sequence controlled service or Directives that are used to configure transceivers at the two ends of the link in a compatible mode; they will be described later in the section and they are collectively referred as External PDU.

- Data Field Construction ID. Bits 4 and 5
  - always '11' in transmission (corresponding to User Defined Data in the protocol language)
  - don't care in reception
- Spacecraft (S/C) ID. 10 bits that identify the S/C which is either the source or the destination of the data contained in the transfer frame, see also the Source or Destination Flag field. In this implementation this bit will contains MER SCID:
  - MER 1 SCID: 'FE'h (TBC)
  - MER 2 SCID: 'FF'h (TBC)
- Virtual Channel ID. One bit:
  - '0' is always transmitted indicating no virtual channel support
  - don't care in reception
- Port ID. Three bits:
  - '000' is always transmitted indicating no support for multiple logical or physical connection port
  - don't care in reception
- Source or Destination Flag, bit 20, with the following definition:
  - '0', will be in the frames transmitted by MER

  - '1' will be in the frames transmitted by Odyssey

- Frame Length. 11 bits indicating the length of the transfer frame in bytes minus 1
- Frame Sequence Number. 8 bits indicating the frame number, incremented when the QoS indicator is '1' (sequence controlled). The counter rolls-over when reaching the value 255.

Set Directives and PLCW [External Protocol Data Units]

As explained before when the combination of the QoS indicator and the PDU Type is '11' the content of the transfer frame data field carries a control directive or a report on the status of the sequence controlled service. Two types of PDU are used by the orbiter and distinguished by the first 2 bits of the data field (PDU Type)

a. Directive PDU

In Figure 8, PDU Type = '00' indicates a Directive or Report Data Unit. The orbiter uses only the Directive PDU (also called command beacon) which is flagged by the next two bits being '00' (PDU Sub-type field), see Figure 9, and is used to configure the SE transceiver in a compatible mode with the orbiter. Since the orbiter always initiates the link, the Directive PDU is always sent by the Orbiter to MER. The Length field, in the orbiter implementation, is fixed at '0100' indicating that the directive contains 4 bytes, with the first 2 bytes reserved for a Set Transmitter directive and the last 2 for a Set Receiver Directive.

	ASM	*Header*	*Data Field*	*CRC*
Directive PDU	3 bytes	5 bytes	5 bytes	4 bytes

	PDU Type	*PDU Subtype*	*Length*	*Set TX Directive*	*Set RX Directive*
Data Field, bits	0,1='00'	2,3='00'	4-7='0100'	8-23	24-39

Figure A-2. Directive PDU

The Set Transmitter and Receiver directives have a common structure as shown in the following Figure, where the specific commands (set mode, data rate, …) will be effective on the receiver or transmitter portion of the MER radio based on the three bits of the Directive Type field (bits 13-15): '000' indicates a Set Transmitter directive, '010' a Set Receiver directive.

Mode	*Rate*	*Modulation*	*Encoding*	*Frequency*	*Directive Type*
0,1,2	3,4,5	6,7	8,9	10,11,12='000'	13,14,15

Figure A-3. Set Receiver and Transmitter Directive

The Frequency field is always set to '000' since there is no support for multiple. The following two Tables will help to decode the setting of parameters based on the value of bits 0-9 in the Set Directive.

The orbiter transceiver will configure its transmitter and receiver sections in a compatible mode respectively with the Set Receiver and Set Transmitter directives.

Table A-2. Set TX Directive - Configure Odyssey Receiver and MER Transmitter

TX Mode	TX Data Rate	TX Modulation	TX Coding
000=Standby	000=8 KBPS	00=FSK	00=Scramble
001=Reliable Bit-Stream	001=32 KBPS	01=PSK	01=Viterbi/ Convolutional
010= Message Bypass	010=128 KBPS	10=PSK Coherent	10=Bypass Coding
011=Unreliable Bit Stream	011=256 KBPS		
100=Tone Beacon (*)			
101=Canister mode			

(*) TX Tone Beacon will command MER to transmit a tone, while the orbiter receiver will be in stand-by - this allows 2-way Doppler measurements with higher carrier SNR

Table A-3. Set RX Directive - Configure Odyssey Transmitter and MER Receiver

RX Mode	RX Data Rate	RX Modulation	RX Coding
000=Standby	000=8 KBPS	00=FSK	00=Scramble
001= Reliable Bit-Stream	001=32 KBPS		
010= Message Bypass	010=128 KBPS	10=PSK Coherent (**)	10=Bypass Coding
011=Unreliable Bit Stream	011=256 KBPS		
100=Tone Beacon			

(**) PSK coherent shall be the same as PSK non-coherent for the receiving section

b. Proximity Link Control Word (PLCW)

PDU Type = '10', in Figure 8, indicates a PLCW used to transmit over the link the status of the Sequence Controlled Service. The data field contains two bytes and its structure is shown in the following Figure and explained below:

	ASM	*Header*	*Data Field*	*CRC*
PLCW	3 bytes	5 bytes	2 bytes	4 bytes

	PDU Type	*Retransmit Flag*	*VC ID*	*Spare*	*Expedited Frame Counter*	*Report Value*
Data Field	0,1='10'	2	3='0'	4='0'	5,6,7='000'	8-15

Figure A-4. PLCW Structure

- Retransmit Flag, bit 2, is always '0' in the implementation for MER and Odyssey
- Virtual Channel ID field, bit 3, is always '0' (no support for multiple VCs) in transmission, don't care in reception
- Expedited Frame Counter is always set to '000' in transmission (counter is not implemented), don't care in reception
- Report Value Field, 8 bits, contains the next expected frame sequence number (0-255).

Appendix B: Acronyms List

APID	Application Packet ID
ARQ	Automatic Repeat Request
ASM	Attached Synchronization Marker
BER	Bit Error Rate
C&DH	Command & Data Handling
CE	Cincinnati Electronics
CCSDS	Consultative Comittee for Space Data Systems
CDU	Command Detector Unit
CRC	Cyclic Redundancy Code
CW	Continuous Wave
DSN	Deep Space Network
EDAC	Error Detection and Correction
FECW	Frame Error Control Word
FER	Frame Error Rate
FIFO	First In First Out
FSK	Frequency Shift Keying
LMA	Lockheed Martin Astronautics
LMTS	Local Mean Solar Time
MER	Mars Exploration Rover
MMO	Mission Management Office
MSP	Mars Surveyor Project
NRZ	Non Return to Zero
PDU	Protocol Data Unit
PLCW	Proximity Link Control Word
PLTU	Proximity Link Transfer Unit
PSK	Phase Shift Keying
QoS	Quality of Service
RHCP	Right Hand Circular Polarization
RS	Reed Solomon
SCID	Spacecraft ID
SDST	Small Deep Space Transponder
SE	Surface Element
SN	Serial Number
SNR	Signal to Noise Ratio
SSO	Sufficiently Stable Oscillator
TBC	To Be Confirmed
TCXO	Temperature Controlled Crystal Oscillator
TMOD	Telecommunications and Mission Operations Directorate
UHF	Ultra High Frequency
ULDL	Uplink/Downlink
VC	Virtual Channel